Electromagnetic fields and environmental health

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Abstract

Invisible electromagnetic fields (EMFs) permeate the modern living environment. They emanate from sources such as electric power lines, home appliances, medical devices, mobile phones and their base stations. Microwave power transmission, a near-future technology that could soon be in practical use, may become a major producer of EMFs. Therefore, electromagnetic environments, including static magnetic fields and low- and high-frequency EMFs, are likely to increase worldwide.

In late May 2011, the International Agency for Research on Cancer (IARC), a sub-agency of the World Health Organization (WHO), met to evaluate the carcinogenicity of radiofrequency (RF) EMFs from mobile phones. This meeting[1] provided a good opportunity for deliberation on the effects of EMFs on human health and to consider future approaches to this issue. The report conclusions, outlined in this paper, suggest there is limited evidence for the carcinogenic effect of RF-EMFs, resulting in RF-EMFs being classified as possibly carcinogenic, but that more studies are necessary to draw quantitative conclusions.

Keywords

Electromagnetic fields, human health, environmental factor, International Agency for Research on Cancer (IARC), World Health Organisation (WHO).

1. Historical background of EMF effects

Electromagnetic radiation is all around us. The light by which we see, the radio waves we use for communication and the X-rays we use to image bones are all types of electromagnetic radiation. Sub-10^{12} Hz electromagnetic fields (EMFs) – which exist at frequencies lower than visible light – and ionizing radiation (X-rays and γ-rays) are different frequencies of electromagnetic radiation and can be found at opposite ends of the electromagnetic spectrum (Figure 1). Sub-10^{12} Hz EMFs are invisible like ionizing radiation but are present all around us in our daily lives.

There is considerable concern about the effects of Sub-10^{12} Hz EMFs on human health but the exact nature of these effects has still to be determined. It is known that X-rays and γ-rays have ionization activity (ie. they can change the ionization state of atoms), which has the ability to damage DNA. This is something low-frequency EMFs do not have. The effects of ionizing radiation on organisms have been studied for many years and although we know

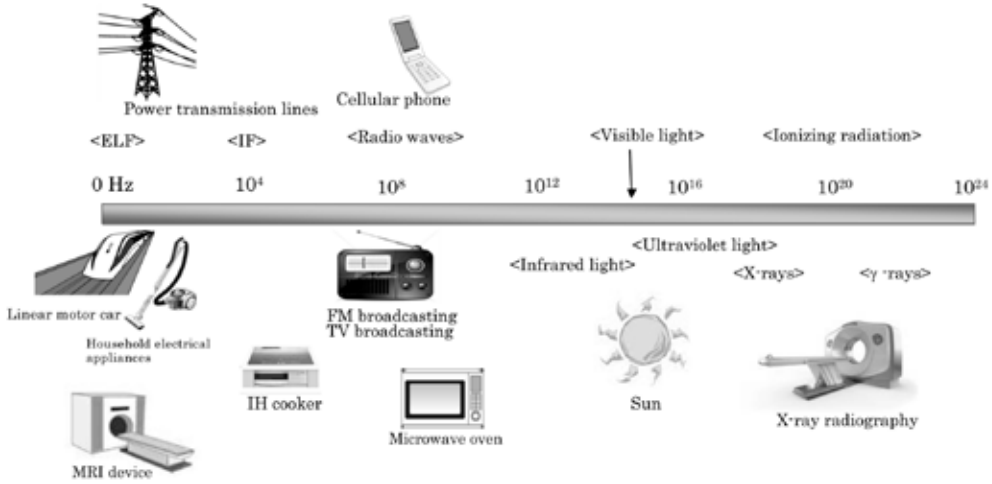

Figure 1. Examples of EMF generators in our living environment and the frequency of their associated EM radiation on the electromagnetic spectrum

about the effects of high-dose radiation, a definite conclusion on the effects of low-dose radiation has yet to be reached. Studies of the effects of Sub-10^{12} Hz EMFs on human health are still in their infancy because of the relatively recent increase of Sub-10^{12} Hz EMFs in our living environment. Therefore, a study of the effects of Sub-10^{12} Hz EMFs is necessary.

Environmental EMFs first became an international issue in 1979 after an American epidemiological study indicated a high incidence of leukaemia in children who lived near power transmission lines (Wertheimer and Leeper 1979). Subsequently, many epidemiological and biological studies of the extremely low frequency (ELF) EMFs induced by power transmission lines were performed on experimental animals and cell cultures in the 1990s. It should be noted that normally when we talk about ELF-EMFs, we mean those in the 3 Hz to 3 kHz frequency range; however, at WHO meetings the ELF frequencies are defined to range from 0 Hz to 100 kHz. Most studies to date have been conducted on the 50 and 60 Hz frequency range.

Several epidemiological studies in Europe and the United States indicated a carcinogenic effect of an ELF-EMF at 0.4 μT (micro-Tesla) and a particular effect on children, with an approximate doubling of the incidence of childhood leukaemia (Ahlbom et al. 2000). However, this conclusion could not be verified after accounting for other factors related to the disease and the results of other epidemiological studies showed no effect of ELF-EMFs on adult and other child cancers (IARC 2002). The effects of radiofrequency (RF) EMFs, including those derived from mobile phones, have been widely investigated internationally since rapid growth in use of mobile phones began in the late 1990s.

The International Agency for Research on Cancer (IARC), a WHO sub-agency, held a meeting in late May 2011 to deliberate the effects of EMFs on human carcinogenicity and to consider future approaches to this issue. RF fields within the 30 kHz to 300 GHz spectrum

were considered in the IARC meeting, where the frequency from cellular phones ranges from 800 MHz to 3 GHz. The conclusions of this meeting are summarized below. It should be noted that the purpose of this report is to discuss EMFs as an environmental factor in daily life. In-depth reports on the effects of EMF on organisms are available elsewhere (Kato 2006; Lin 2009; Verschaeve et al. 2010).

2. Research on the effects of RF-EMFs

2.1 Outline

Studies on the biological effects of non-ionizing radiation EMFs have shown that low frequency EMFs (≤100 kHz) have a "neuronal stimulation effect" and high frequency EMFs (≥100 kHz, including RF-EMFs) have a "thermal effect". Particularly strong RF-EMFs are used clinically in hyperthermic cancer therapy and treatment for rheumatism and neuralgia, owing to their thermal effects in the human body. However, the effects of RF-EMFs in the living environment have not been widely investigated and many issues remain unclear. The use of mobile phones has grown rapidly and these phones are used in close proximity to the human brain. Therefore, there is a concern that mobile-phone-derived RF-EMFs may have harmful effects on the brain, such as promoting brain tumours. The so-called "non-thermal effect" of RF-EMFs is also an area of intense debate, particularly with regard to the effect on children.

Many international studies of the biological effects of RF-EMFs have been undertaken in Europe, the United States and Japan since 2000, with scientifically reliable results produced in studies of cells, animals and humans. The major criteria for evaluating the effects of EMFs are shown in Table 1, which summarises the subject and evaluation criteria for *in vitro* (cellular), *in vivo* (experimental animal), epidemiological and human body-based studies. The general focus of EMF studies has been on the relation between EMF carcinogenicity, where all studies are considered equally important irrespective of whether the results were obtained in humans, animals or cells. However, for evaluating effects that may occur in humans, the results are weighted so that epidemiological study is more significant than experimental animal study, which, in turn, is more significant than cellular study. When looking at the accuracy and reproducibility of the study, the results of cellular studies have greater accuracy and reproducibility than experimental animal studies, which, in turn, have greater accuracy and reproducibility than epidemiological studies. Therefore, it is most difficult to get accurate and reproducible results for the studies that tell us most about the effects of EMFs on humans.

2.2 Epidemiological studies of RF-EMFs

As discussed above, epidemiological studies are more applicable than in vitro and in vivo studies when evaluating the effects of RF-EMFs in daily life. However, humans live in

Table 1. Major criteria for evaluating the influence of electromagnetic fields

Research category	Subject	Evaluation criteria
In vitro study	Cells	Cell proliferation, DNA synthesis, chromosomal aberration, sister chromatid exchange, micronucleus formation, DNA strand breaks, gene expression, signal transduction, ion channels, mutation, transformation, cell differentiation, cell cycle, apoptosis.
In vivo study	Laboratory animals (rat, mouse, etc.)	Carcinogenesis (lymphoma, leukaemia, skin cancer, mammary gland tumor, liver cancer), reproduction and development (implantation rate, fetal body weight, teratogenesis), abnormal behavior, neuroendocrinology (mainly melatonin), immune function, blood brain barrier.
Epidemiological study	Human	Carcinogenesis and cancer death (brain tumour, childhood and adult leukemia, breast cancer, melanoma, lymphoma), reproductive ability, spontaneous abortion, Alzheimer's disease.
Influence on human body	Human	Psychological and physiological influences (fatigue, headache, anxiety, lack of sleep, brain waves, electrocardiogram, memory), neuroendocrinology (mainly melatonin), immune function.

many different environments and, as a result, it is very difficult to investigate single factors in one study. The results will always depend on the choice of the subject population and other selection biases while the influence of other factors, such as anomalous results, on the statistical evaluation cannot be excluded.

International epidemiological studies of the carcinogenicity of mobile-phone-derived RF-EMFs are ongoing. The large-scale Interphone study was conducted by research groups from 13 nations, including Japan, the United Kingdom and Sweden (but excluding the United States). This work was organized by the IARC as a case-control study of various types of brain tumour. The IARC compiled the results from all participating countries and published a summary of the conclusion in a press release in May 2010 (WHO 2010; Cardis et al. 2011). The study looked at the odds ratio (OR) – the ratio of the odds of cancer occurring in the study group as a result of mobile phone use to the odds of it occurring in the control group – to look for an increased likelihood of cancer through mobile phone use. Therefore, a reduced OR implies a decrease in the risk of cancer. This study focuses on two common forms of brain tumour, glioma (malignant) and meningioma (benign). The results were as follows:

1) A reduced OR, but not to a significant level, for the presence of glioma and meningioma was associated with a history of regular mobile phone use.

2) There was no elevation of the OR for the presence of glioma and meningioma for ≥10 years after first phone use.

3) In the 10th [highest] decile of recalled cumulative call time (≥1640 h), the OR for glioma was increased by 1.40 (between 1.03-1.89 in the 95 per cent confidence interval).

In the press release, it was concluded that no elevated OR for glioma or meningioma was observed for ≥10 years after first phone use. There were suggestions of an increased risk of glioma, and a smaller increased risk of meningioma, in the highest decile of cumulative call time in subjects who reported regular phone use on the same side of the head as their tumour and, for glioma, for tumours in the temporal lobe. However, biases and errors limit the strength of the conclusions that can be drawn from these analyses and prevent a causal interpretation (Cardis et al. 2011).

Other epidemiological studies have shown no evidence of carcinogenicity caused by mobile-phone-derived RF-EMFs. However, a Swedish meta-analysis of epidemiological studies showed that the incidence of glioma was three times higher in mobile users who have ≥2000 hr accumulative lifetime use (Hardell et al. 2011) and an epidemiological study in Japan suggested increased acoustic neuroma in people who speak on a mobile phone for ≥20 min each day (Sato et al. 2011). There is no clear evidence of an association between occupational exposure to RF-EMFs and cancer, including brain tumours, leukaemia and lymphoma, or between carcinogenicity and electric waves transmitted from radio/television towers and base stations. The relationship between carcinogenicity and mobile phone use by children was investigated in the now completed Cefalo project in three countries, including Denmark (Aydin et al. 2011), and is currently under examination in the ongoing Mobi-Kids project in 16 countries, including Japan and Korea (Mobi-Kids 2009).

2.3 Animal and cellular studies of RF-EMFs

In 1997, a study using transgenic mice showed that the incidence of leukaemia was increased by RF-EMF exposure (Repacholi et al. 1997) and since then the effect of RF-EMF on carcinogenicity has been widely evaluated. Animal studies have been conducted mainly in Europe, the United States and Japan. Studies using long-term (two-year) exposure and in animals with a high cancer incidence showed almost no effects of RF-EMFs (News: *Lancet Oncology* 2011). However, studies of co-carcinogenicity (chemical agents and RF-EMFs) have shown an increase in carcinogenicity (Szmigielski et al. 1982; Tillmann et al. 2010). Most *in vitro* studies have shown reliable results (ie. a higher likelihood) for genotoxicity, mutation, immune system effects, gene expression (RNA and protein), signal transduction, apoptosis and proliferation rate. There is no clear evidence of the mechanism of action of RF-EMFs under non-thermal conditions (News: *Lancet Oncology* 2011).

3. IARC evaluation of RF-EMF carcinogenicity

The WHO launched the International EMF Project in 1996 to address growing questions about the relationship between EMFs and human health. Sixty countries are now participating in this project. The IARC evaluated the carcinogenicity of ELF-EMFs in 2001 and the WHO held a task conference that included evaluating health effects (except carcinogenicity) in 2006.

Based on these meetings, the IARC and WHO published the IARC monograph vol. 80 (2002) and the ELF-Environmental Health Criteria (EHC) (WHO, N°238, 2008), respectively. Next came an IARC conference to evaluate the carcinogenicity of RF-EMFs, held from May 24 to 31 2011, which brought together a total of 30 Working Group members from 15 countries and reached the following conclusions.

1) Epidemiological studies. A comprehensive evaluation showed that there was "limited evidence in humans" for an RF-EMF effect, based on the positive results of some studies.

2) Animal studies. A similar comprehensive evaluation showed that there was "limited evidence in experimental animals" for an RF-EMF effect, based on the positive results of some co-carcinogenicity studies, although many gave negative results.

3) Other studies with endpoints relevant to mechanisms of carcinogenesis. It was determined that there was "weak mechanistic evidence", although some studies showed positive results.

4) Overall evaluation. The Working Group determined that both epidemiological studies and studies of carcinogenicity in experimental animals showed "limited evidence" for an effect of RF-EMFs. The overall evaluation of RF-EMF carcinogenicity was classified as "Group 2B (possibly carcinogenic to humans)".

Table 2. Carcinogenicity classification by IARC

Classification and classification criteria of carcinogenicity	Results of classification [953 cases]
Group 1: carcinogenic to humans	Asbestos, cadmium and cadmium compounds, formaldehyde, *γ-rays, *solar radiation, *X-rays, alcoholic beverages, coal tars, passive smoking, tobacco smoking, *ultraviolet radiation (wavelengths 100-400 nm, encompassing UVA, UVB and UVC), *sunlamps and sunbeds (see ultraviolet-emitting tanning devices). [108 cases including others]
Group 2A: probably carcinogenic to humans	Acrylamide, adriamycin, benz[a]anthracene, benzo[a] pyrene, cisplatin, methyl methanesulfonate, diesel engine exhaust, polychlorinated biphenyls. [64 cases including others]
Group 2B: possibly carcinogenic to humans	Acetaldehyde, AF-2, bleomycins, chloroform, daunomycin, lead, *magnetic fields (extremely low frequency), merphalan, methylmercury compounds, mitomycin C, phenobarbital, *radiofrequency electromagnetic fields, coffee (urinary bladder), gasoline. [272 cases including others]
Group 3: unclassifiable as to carcinogenicity to humans	Actinomycin D, ampicillin, anthracene, benzo[e]pyrene, cholesterol, diazepam, *electric fields (extremely low frequency), *electric fields (static), ethylene, *fluorescent lighting, magnetic fields (static), 6-mercaptopurine, mercury, methyl chloride, phenol, toluene, xylenes, tea. [508 cases including others]
Group 4: probably not carcinogenic to humans	Caprolactam (nylon material). [1 case]

*Environmental factors related to EMFs and radiation.

Examples of the carcinogenicity classification of the IARC are shown in Table 2, which classifies potential carcinogens in order of their carcinogenicity. Category "2B" for RF-EMFs in this evaluation is based on the conclusion that the association between mobile-phone-derived EMFs and brain tumours is based on "limited evidence". An outline of this result was published in a press release (News: *Lancet Oncology*, Volume 12, 2011). It should be noted that the meeting focused on a qualitative assessment of carcinogenicity, rather than a quantitative evaluation. This is an important point because it is possible that the media may have reported misleading information on this issue.

The details of the meeting are to be published in IARC monograph vol. 102 in 2013. Based on the IARC classification of RF-EMF carcinogenicity, the WHO plans to hold a meeting to evaluate the effects of RF-EMFs on overall health, include carcinogenicity, and to develop RF-Environmental Health Criteria in 2014 or later. For children, two large epidemiological studies are in progress (Aydin et al. 2011; Mobi-Kids 2009). The precautionary principle for limiting the use of mobile phones by children will be also discussed at the next RF-EHC meeting.

4. Summary

Engineering technology associated with EMFs, including that used in mobile phones, has advanced markedly. Simultaneously, EMFs have started to be viewed as a significant factor in our environment. ELF- and RF-EMFs have no ionizing activity and in this way differ from the ionizing radiation of X-rays and γ-rays. Although it is unlikely that, given their relatively low energy, EMFs damage cellular DNA directly, public concerns about electromagnetic fields are similar to concerns about radiation. In this article, a simple explanation of the scientific evidence has been given where possible, with accurate information that explains if an issue has yet to be resolved. The use of EMFs in living environments, including the wireless transmission of power for mobile phones, computers and electric vehicles, can only increase. Therefore, there is likely to be an increase in the size and number of electromagnetic environments. Further research will be important in evaluating EMF effects accurately and studies to examine unresolved problems should be promoted so we can draw more definitive conclusions on the role of EMFs in our living environment.

Notes

[1] The author of this article participated in this meeting as a member of the Working Group. The Working Group was divided into four subgroups: exposure, epidemiology, animal cancer studies and mechanistic/other relevant data. The author belonged to the last subgroup and worked on assessing the RF exposure effects on cellular and gene levels, including mechanism analysis.

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